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(19)

(54) AN ELECTROPHORETIC SUSPENSION

(71) We, THE PLESSEY COMPANY LIMITED, a British Company of 2/60 Vicarage Lane, Ilford, Essex, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to working fluids for electrophoretic image reproduction devices.

According to the invention there is provided a working fluid for an electrophoretic image reproduction device including a dispersion of finely divided particles which exhibit electrophoresis, suspended in a suspension medium, each of the said particles including a body of an inactive organic compound at least partially surrounded by a layer of a dielectric material which is adapted to collect the required charge for effecting particle transportation, wherein the body effects a density match between the suspension medium and the said particles.

The said body can be impregnated with a dye, for example a fluorescent dye, which makes the body light reflective and with this arrangement the thickness of the dielectric layer would be arranged so that the layer is light transparent. Alternatively, the dielectric layer could be rendered light reflective, the said body being adapted to effect a density match between the suspension medium and the particle in both of these arrangements.

According to a preferred feature of the invention, a working fluid as outlined in a preceding paragraph is provided which also includes within the said body a core of a light reflective material, the said body being of a light transparent material which is adapted to effect a density match between the suspension medium and the particle. The core is preferably of magnesium although other suitable light reflective materials, for example hexagonal boron nitride and heavily-doped silicon could be used. Heavily doped silicon being silicon in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}, (Phys Rev *96* (1), 28—35 (1954). The said body can be of a polymer such as poly(acrylonitrile) or other organic compounds.

The dielectric layer can be of titanium dioxide (TiO_2) or other dielectric oxides such as SiO_2 or Al_2O_3 or hydrous forms of these oxides.

The foregoing and other features according to the invention will be better understood from the following description with reference to drawings accompanying the Provisional Specification, in which:

FIGURE 1 diagrammatically illustrates an electrophoretic image reproduction device in a cross-sectional side elevation,

FIGURE 2 diagrammatically illustrates in a cross sectional side elevation the structure of the electrophoretic particles of a working fluid according to the invention, and

FIGURE 3 illustrates contours of reflectivity (at normal incidence) for the interface between a semi-infinite sheet of material with a refractive index $n+ik$ and poly(acrylonitrile).

An electrophoretic image reproduction device is diagrammatically illustrated in FIGURE 1 of the drawings in a cross-sectional side elevation and includes a working fluid 1 enclosed in a housing 2 consisting of a hollow open-ended plastics container 3 closed at each end by transparent electrically insulating members 4 and 5, for example of glass, polyester, cellulose acetate, regenerated cellulose or polyethylene. Transparent electrodes 6 and 7, for example, of cuprose oxide or tin oxide, are respectively attached to the inner surfaces of the members 4 and 5 and are in contact with the electrophoretic suspension medium 1.

The working fluid 1 includes a dispersion of finely divided particles *1b* which exhibit electrophoresis, suspended in a suspension medium *1a* such as isopropyl alcohol or olive oil. The particles *1b* are shown greatly enlarged for the sake of clarity but, in practice, it is thought that the particles *1b* must not be greater than 1/10 of the spacing between

the electrodes 6 and 7.

In operation, the electrodes 6 and 7 are connected to a direct voltage source (not illustrated), the polarity of which can be reversed. In the absence of an electric field between the electrodes, the particles 1*b* are, as is illustrated in FIGURE 1, distributed uniformly throughout the suspension medium 1*a*. If, for example, the particles 1*b* are white and the suspension medium 1*a* is black, the working fluid 1 will, in the absence of an electric field, appear grey when illuminated by an incandescent lamp. When the grey working fluid is subjected to a unidirectional electrical field as a result of the application of the direct voltage source to the electrodes 6 and 7, the particles 1*b* are caused to move electrophoretically in the direction either of the cathode electrode or the anode electrode depending on the polarity of their charge. If, for example, the particles 1*b* acquire a negative charge and the electrode 6 is the anode electrode, then the particles 1*b* will migrate towards, and will be deposited on the surface of, the electrode 6. Under these conditions spatial distribution of the particles 1*b* in the suspension medium 1*a* will be different from the initial uniform distribution illustrated in FIGURE 1 and, therefore, the working fluid 1 will have different optical reflectance properties from those of the original working fluid illustrated in FIGURE 1. With the exampled working fluid given above, the electrophoretic image reproduction device will, under these conditions appear white at the surface 2*a* and black at the surface 2*b*.

The colour appearing at the surfaces 2*a* and 2*b* of the image reproduction device of FIGURE 1 can be reversed by reversing the polarity of the voltage that is applied between the electrodes 6 and 7.

The particles 1*b* used in the working fluid 1, are, therefore, required to fulfil three quite separate functions in that the particles must be able to (a) scatter light efficiently, (b) match the density of the suspension medium 1*a* and (c) have a high mobility, which in turn means a high zeta potential.

In a working fluid according to the invention these three functions are fulfilled by utilising electrophoretic particles having, as is diagrammatically illustrated in FIGURE 2 of the drawings in a cross-sectional side elevation, a three-layered structure.

The function (a) will be effected by the core 8 which must, therefore, be formed from a light reflective material, the function (b) will be effected by a layer 9 of a light, transparent plastics material which surrounds the core 8 and the function (c) will be effected by a layer 10 of a dielectric material which is formed on the surface of the plastics layer 9.

A list of materials that may be suitable for the core 8 are given in the following table. All the materials have a density value less than 3.0, the optical constants n and k refer to the complex refractive index $n+ik$ and the optical constant R refers to material reflectivity and is given by the formula:

$$R = \frac{(n-n_o)^2 + k^2}{(n+n_o)^2 + k^2}$$

Material	Material Density	Optical Constants n	k	R (observed)
B_2S_3	1.55			
Mg	1.74		2–4	∿0.72
Be	1.85			
Mg_2Si	1.94	3½–5	0–2	0.35–0.65
Al_2S_3	2.02			
Mg_3P_2	2.06			
BP	2.08			
BN (hex)	2.25			
Si	2.33	3¾–5	0	0.33–0.45
B	2.34, 2.37			
BeS	2.36			
B_2O_3	2.46	1.62		
Al	2.70		2¼–6	∿0.70
Mg_3N_2	2.71			
MgS	2.84	2.27		
AlP	2.85	3.4		

The choice of a material for the core 8 is dependent on factors such as availability, ease of manufacture and cost. From the list of materials which is by no means exhaustive, the three materials that are easily available and ideally suited for the core of the electrophoretic particles 1*b* are magnesium, hexagonal boron nitride and heavily-doped silicon, i.e. silicon in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}.

The plastics layer 9 can be of a polymer such as poly(acrylonitrile) for which n_o = 1.51 and k_o = 0.

FIGURE 3 illustrates contours of reflectivity (at normal incidence) for the interface between a semi-infinite sheet of material with a refractive index n+ik and poly(acrylonitrile). The reflectivity contours for the core 8/layer 9 construction of FIGURE 2 will be somewhat different to the contours of FIGURE 3, but these contours a reconsidered to be adequate for first- order selection.

It can be seen from FIGURE 3 that, for really high values of reflectivity, it is more important to have high values of k than of n and for this reason the preferred material for the core 8 is magnesium.

In another working fluid according to the invention the three-layered structure of FIGURE 2 is replaced by a two-layered structure, the layer 9 and the core 8 being replaced by a single body of an inert polymer or other organic compound which is surrounded by the dielectric layer 10 of FIGURE 2.

The function (b) referred to in a preceding paragraph will be effected by the single body of the two-layered structure and the function (c) will, as with the structure of FIGURE 2, be effected by the dielectric layer.

In one arrangement of the two-layer structure, the single body is impregnated with a dye, for example a fluorescent dye which makes the body light reflective and thereby

adapted to effect the function (a) referred to in a preceding paragraph. With this arrangement the thickness of the dielectric layer would be arranged so that the layer is light transparent.

In an alternative arrangement of the two-layered structure the function (a) is effected by the dielectric layer which would be of a thickness that substantially prevents light transmission therethrough.

The single body of the two-layered structure can be of either poly(acrylonitrile), or polyethylene, or poly(trimethylpentene).

The dielectric layer which can be formed from titanium dioxide TiO_2, or other dielectric oxides such as SiO_2, or Al_2O_3 or hydrous forms of these oxides, must be such that sufficient charge can be collected for effecting particle transportation in the suspension medium 1*a*. It is thought that it may not be necessary for the dielectric layer to be formed in a continuous layer.

Since the dielectric layer will be deposited on a polymer during the production of the particles 1*b*, it will be necessary, during deposition of the dielectric layer, to utilise low temperature reactions such as the hydrolysis of isopropoxides or chlorides, for example,

$$Al(OC_3H_7)_3 + 3H_2O \rightarrow Al(OH)_3 + 3HOC_3H_7$$

$$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$$

It is to be understood that the foregoing description of specific examples of this invention is made by way of example only and is not to be considered as a limitation in its scope.

WHAT WE CLAIM IS:—

1. A working fluid for an electrophoretic image reproduction device including a dispersion of finely divided particles which exhibit electrophoresis, suspended in a suspension medium, each of the said particles including a body of an inactive organic compound at least partially surrounded by a layer of a dielectric material which is adapted to collect the required charge for effecting particle transportation, wherein the body effects a density match between the suspension medium and the said particles.

2. A working fluid as claimed in claim 1 wherein the said body is impregnated with a dye which makes the said body light reflective and wherein the thickness of the dielectric layer is arranged so that the layer is light transparent.

3. A working fluid as claimed in claim 2 wherein the dye is a fluorescent dye.

4. A working fluid as claimed in claim 1 wherein the dielectric layer is light reflective.

5. A working fluid as claimed in claim 1 which also includes within the said body a core of a light reflective material, the said body being of a light transparent material which is adapted to effect a density match between the suspension medium and the particle.

6. A working fluid as claimed in claim 5 wherein the core is of magnesium.

7. A working fluid as claimed in claim 5 wherein the core is of either hexagonal boron nitride or silicon, in which the Fermi level is degenerate due to the presence of impurity doping at levels above 10^{19} atoms cm^{-3}.

8. A working fluid as claimed in any one of the preceding claims wherein the said body is of either poly(acrylonitrile), or polyethylene, or poly(trimethylpentene).

9. A working fluid as claimed in any one of the preceding claims wherein the dielectric layer is of either TiO_2, or SiO_2, or Al_2O_3, or hydrous forms of these oxides.

10. A working fluid for an electrophoretic image reproduction device as claimed in claim 5 substantially as hereinbefore described with reference to the drawings accompanying the provisional specification.

11. A working fluid for an electrophoretic image reproduction device as claimed in claims 1 to 4 substantially as hereinbefore described.

12. An electrophoretic image reproduction device which includes a working fluid as claimed in any one of the preceding claims.

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1465701 PROVISIONAL SPECIFICATION

1 SHEET This drawing is a reproduction of the Original on a reduced scale.

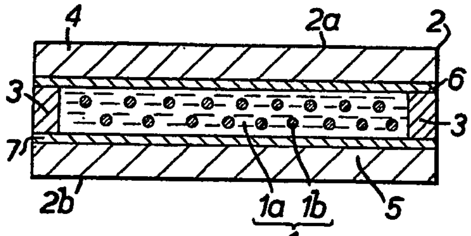

FIG. 1.

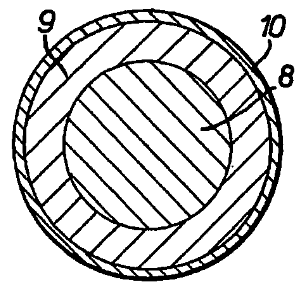

FIG. 2.

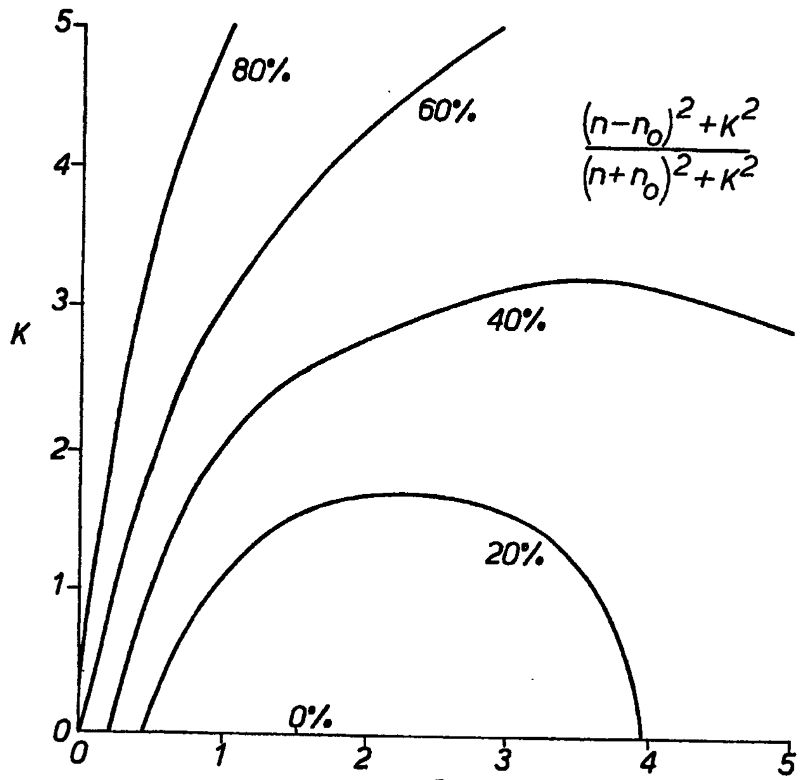

FIG. 3.